ANTI-TARNISH SILVER ALLOY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 60/466,207, filed on April 29, 2003, which is herein incorporated by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates generally to silver alloys, more particularly to sterling silver alloys having improved tarnish resistance for use in materials such as jewelry and tableware, as well as electrical applications.

BACKGROUND OF THE INVENTION

[0003] Silver alloys has been used for the manufacture of articles such as decorative jewelry and tableware, as well as other formed, extruded and molded pieces for many years. The main element in these alloys is silver, a precious metal desirable for its bright white color tone. However, use of pure silver alone is not feasible due to its lack of inherent hardness.

[0004] Alloys of silver have traditionally been used to improve hardness and other qualities. The use of copper (Cu) is known for improving the hardness of silver. Other additional elements can be useful in imparting desirable qualities to silver metal. Advantages to the use of various silver alloys include their amenability to being cast from molten metal, malleability, and strength or hardness.

[0005] The presence of copper in a silver alloy can be problematic as copper has a propensity to form discoloring sulfides and chlorides. Additionally, silver-copper alloys often oxidize to form a black- or red-colored blemish commonly known as "fire scale". It is believed that fire scale is copper oxide. The cupric variety will produce a blackened blemish, whereas the cuprous variety will form a reddish blemish. In either case, this blemish is not limited to the surface of the article, as in the case of superficial tarnish (typically silver sulfide), but may

penetrate the article more deeply. In some cases, the penetration is such that the defect or blemish cannot be removed by buffing and polishing.

[0006] Consequently, a disadvantage of currently available silver alloys, which include substantial amounts of copper to maintain hardness, is their tendency to form fire scale and/or become tarnished. Such tarnish can occur from oxidation which results from exposure to air and/or sulphurization which results from exposure to sulfur from atmospheric contamination, or, for example, skin contact. The discoloration is usually treated with an appropriate polish to remove the discoloration. Such treatment must be performed regularly in order to maintain the beauty and condition of the article. The discoloration is a principal drawback to greater popularity of silver jewelry.

[0007] A number of silver alloys have been developed to attempt to minimize the amount of discoloration occurring on the surface of articles made from such alloys, while maintaining advantageous qualities of strength and the like. U.S. Patent No. 3,811,876 to Harigaya et al. discloses a silver alloy including tin (Sn), zinc (Zn) and indium (In), with a balance being silver. The combination of Sn, Zn and In with the silver was found to have a synergistic effect in reducing sulphurization of the alloy. However, these alloys will lose their sulphurization resistance if contacted with conventional phosphoric flux containing polish used as deoxidizing agents.

[0008] U.S. Patent No. 5,817,195 to Davitz discloses a silver alloy including nickel (Ni), metal silicate, Zinc (Zn), Copper (Cu), with a balance being silver. The alloy may also contain up to 0.5% Indium (In).

[0009] U.S. Patent No. 5,021,214 to Sasaki et al. discloses a silver alloy including indium (In), aluminum (Al), and copper (Cu). The use of indium and aluminum is indicated as a substitute for conventional palladium (Pd) in providing xanthation resistance without the expense associated with the use of palladium.

[0010] U.S. Patent No. 6,139,652 to Carrano discloses silver alloys. The alloys include silver and an added element which consists essentially of at least one oxide of aluminum, antimony, cadmium, silicon, titanium, and zinc. The oxide is effective to improve tarnish resistance of the alloy. By using certain processing techniques, it is possible to also increase the annealed hardness of the alloy.

[0011] U.S. Patent No. 4,973,446 to Bernhard et al discloses silver alloys. The alloys consist essentially of silver, silicon, boron, zinc, copper, tin and indium. The alloy provides an improved porosity and grain size as well as reducing fire scale. However, this alloy includes copper in amounts that contribute to tarnish.

[0012] There is an acute need for silver alloys which maintain the advantage of strength and ease in manufacture while reducing the amount of corrosion and/or tarnish of articles made therefrom.

SUMMARY OF THE INVENTION

[0013] The present invention provides a silver alloy having desirable properties including tarnish resistance as well as having sufficient strength and workability to be useful in making a wide variety of silver articles. The silver alloy is particularly useful in making fine sterling silver jewelry.

[0014] A silver alloy is provided including at least about 85% silver, with the balance including zinc, copper, indium and tin. Optionally, the alloy also includes iron or gold. Preferably, the alloy contains one or more relatively small amounts of, silicon, manganese, boron, bismuth, cobalt, chromium and lead. In certain applications, all of the above elements are present, in addition to vanadium, cerium, iridium, and zirconium.

[0015] In a further aspect of the present invention, a sterling silver alloy is provided including silver in a range of from about 92.5% to about 95% by weight with a balance including

zinc in an amount up to about 5% by weight, copper in an amount up to about 1.5% by weight, indium in an amount up to about 0.2% by weight, tin in an amount up to about 2% by weight; and at least one metal selected from the group of: gold (Au), copper (Cu), indium (In), zinc (Zn), tin (Sn), iron (Fe), silicon (Si), manganese (Mn), boron (B), bismuth (Bi), cobalt (Co), chromium (Cr), lead (Pb), vanadium (V), cerium (Ce), iridium (In), and zirconium (Zr).

[0016] Also provided is a method of making an article from an alloy according to the present invention including the steps of pre-forming an alloy of the invention into a pre-formed piece, melting the piece, casting the melted piece into a mold to form a cast article, cooling the cast article, and removing the cooled article from the mold. Optionally, residual alloy from the casting step may be reworked into a virgin alloy for use in making subsequent articles.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

[0018] The figure is a photograph illustrating the degree of tarnish of silver alloys according to the invention identified as QLS-7 and QLS-8 as compared to known silver alloys identified as QLS-9, QLS-10, NAGAOKA and ULTRAFINE, after exposure to a tarnish producing environment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] The inventor has found that a highly tarnish resistant silver alloy, suitable for use in a variety of products, may be obtained by combining certain additional metals with silver. The alloy of the present invention provides an alloy of superior quality which possesses sufficient hardness without the necessity to perform additional steps of annealing or reheating. Due to the properties of tarnish resistance and hardness, the alloy of the present invention is particularly suited for use in making fine silver jewelry.

Composition of the Alloy

[0020] In general, the alloy includes at least about 85% silver. The amount and quality of silver present in the alloy is dictated by the intended use of the alloy. Generally, at least about 85% is necessary in order to maintain sufficient conductivity and other electrical properties for use in electric contacts and the like. In order for the quality of the silver alloy to be considered "sterling" the alloy must include at least 92.5% by weight of silver. Preferably the silver used has a purity of at least about 99.99%.

[0021] The presence and amount of elements added to silver in the alloy of the present invention are dictated by the ultimate use for the alloy. In one embodiment of the invention, the alloy includes at least from about 85% to about 95% of silver with the balance being made up of zinc, copper, indium, tin. Optionally, a small amount of iron may also be included. Desirably, the composition includes relative amounts of these elements in descending order, with the greatest amount being zinc and the least being iron.

[0022] Table 1 is a listing of elements which may be present in the silver alloy of the present invention including the preferred amount of each element. The silver alloys of the present invention contain as a minimum: silver, zinc, copper, indium and tin. The preferred ranges are indicated in Table 1. In addition, one or more other metals are added to enhance the features of the alloy. These metals and their preferred ranges are also listed in Table 1.

TABLE 1

Element	Range of Weight Percent
Silver (Ag)	85% to 95%
Zinc (Zn)	>0% to 5%
Copper (Cu)	>0% to 2%
Indium (In)	>0% to 1%
Tin (Sn)	>0% to 2%
Iron (Fe)	0% to 1%
Gold (Au)	0% to 2%
Silicon (Si)	0% to 0.1%
Manganese (Mn)	0% to 0.1%

Element	Range of Weight Percent
Boron (B)	0% to 0.1%
Bismuth (Bi)	0% to 0.1%
Cobalt (Co)	0% to 0.1%
Chromium (Cr)	0% to 0.1%
Lead (Pb)	0% to 0.1%
Vanadium (V)	0% to 0.1%
Cerium (Ce)	0% to 0.1%
Iridium (In)	0% to 0.1%
Zirconium (Zr)	0% to 0.1%

[0023] The relative amounts of each element will be chosen to optimize the desired characteristics for each application. Generally, each component provides certain desirable characteristics, when provided in an alloy in a useful amount.

[0024] The presence of zinc adds to the whiteness of the alloy. Copper acts as a conventional hardening agent and adds malleability. Indium adds brilliance, ductility, and facilitates casting of the alloy. Tin adds to the hardness, malleability, ductility, and solderability of the alloy. Iron adds to the hardness of the alloy.

[0025] The alloy of the invention maintains superior color, while providing tarnish resistance and other qualities by the combination of the indicated elements in the chosen ranges. Conventionally, a certain amount of copper is necessary to provide sufficient hardness to the alloy. Experimentation with varying percentages of copper, however, indicates that levels usually used in silver alloys may result in less resistance to tarnish in the alloy of the present invention. The alloy of the present invention maintains sufficient hardness even in the presence of lower amounts of copper. Desirably, the amount of copper in the alloy is maintained below about 1.5% by weight of the composition.

[0026] The elements may be provided in any form, including for example, oxides, chlorides or elemental form. Preferably, the elements of the present invention are added in their elemental form as opposed to, for example, oxides or chlorides.

[0027] Each of the additional elements, either alone or in appropriate combination, can provide certain additional advantageous qualities to the final product being formed therefrom. These qualities include the ability to be cast, extruded, welded or soldered, reduction or elimination of fire scale, malleability and the ability to draw the alloy into a fine wire.

[0028] Useful qualities associated with the use of these additional elements in appropriate quantities include the following. Silicon acts to prevent fire scale, acts as a deoxidant, reduces the porosity of the recast alloy, and has a slight hardening effect. Manganese adds hardness and durability to the end product. Boron contributes to the elimination of fire scale. Bismuth aids in castability and solderability and also lowers the melting point of the alloy. Cobalt aids in preventing tarnish. Chromium contributes to the luster and hardness of the finished product. Lead adds to the malleability and castability of the alloy and helps control the melting range of the alloy. Vanadium adds brightness, ductility, resistance to oxidation and increases electrical conductivity. Cerium reduces adhesion of slag particles during casting or other manufacturing processes. Iridium adds corrosion resistance and hardness to the alloy. Zirconium improves the conductivity of the alloy for use in electrical contacts and for other electrical applications.

[0029] Notably, cobalt separates from molten silver. However, when using certain preferred embodiments of the invention, it is possible for cobalt to dissolve into the molten silver. In this instance, the cobalt is able to contribute significantly to the anti-tarnish properties of the alloy.

[0030] The addition of various combinations of additional elements to the alloy of the invention can provide specialized alloys for various products. The specialized alloys maximize the desired qualities for particular products made therefrom. The following embodiments are illustrative of specialized alloys and products for which they are designed.

[0031] In a further embodiment of the present invention, a tarnish resistant silver alloy is provided including at least about 90% by weight of silver, from about 0.5% to about 1.5% of copper, from about 2% to about 5% of zinc, about 0.1% of indium and about 0.2% gold. Preferably, the alloy includes 93.8% silver, 1.25% copper, 4.5% zinc and 0.1000% indium. More preferably, the alloy further includes at least one of: iron, silicon, manganese, boron, bismuth, cobalt, chromium and lead. Most preferably, the alloy includes each of the elements listed above.

[0032] Another embodiment of the present invention provides a tarnish resistant silver alloy useful in making extruded metal, including: from about 92% to about 95% by weight silver; from about 2% to about 5% by weight of zinc, from about 1% to about 1.5% by weight of copper and from about 0.05% to about 0.2% by weight of indium. Table 2 shows a particularly preferred embodiment of a tarnish resistant silver alloy useful in making extruded metal for use in jewelry.

TABLE 2

Element	Preferred Weight %
Silver (Ag)	94.848
Zinc (Zn)	0.5
Copper (Cu)	1.25
Indium (In)	0.10
Tin (Sn)	0.5
Iron (Fe)	0.005
Gold (Au)	0.2500
Silicon (Si)	0.035
Manganese (Mn)	0.001
Boron (B)	0.001
Bismuth (Bi)	0.002
Cobalt (Co)	0.0015
Chromium (Cr)	0.0005
Lead (Pb)	0.002
Vanadium (V)	0.001
Cerium (Ce)	0.001
Iridium (In)	0.001

Element	Preferred Weight %
Zirconium (Zr)	0.001

[0033] In a further embodiment of the present invention, a tarnish resistant silver alloy useful in making tea kettles is provided, including: from about 92% to about 95% by weight of silver, from about 2% to about 5% by weight of zinc, from about 1% to about 1.5% by weight of copper and from about 0.05% to about 0.2% by weight of indium. Table 3 shows a particularly preferred embodiment of a tarnish resistant silver alloy useful in making teapots.

TABLE 3

Element	Preferred Weight %
Silver (Ag)	93.0
Zinc (Zn)	3.895
Copper (Cu)	1.25
Indium (In)	0.10
Tin (Sn)	0.5
Iron (Fe)	0.005
Gold (Au)	0.300
Silicon (Si).	0.04
Boron (B)	0.001
Bismuth (Bi)	0.002
Cobalt (Co)	0.0015
Chromium (Cr)	0.001
Vanadium (V)	0.001
Cerium (Ce)	0.001
Iridium (In)	0.001
Zirconium (Zr)	0.001

Methods of Making Articles from the Alloy

[0034] Preparation of the silver alloy of the present invention may be performed using founding methods known to those skilled in the art. In one aspect of the invention, the alloy is formed into pellet-like shot for later use in casting processes. To form the shot, the alloy may be melted in a crucible to a suitable temperature. Depending on the melting point of the individual elements, the temperature will be at least the melting point of the element having the highest

melting point. The alloy may then be poured into water and the granules so formed shaped into the form of shot for later use and handling.

[0035] In one method of making articles using the silver alloys of the invention, a user may pour a desired quantity of shot, melt it, and then cast it into the specific form desired. Investment casting is in widespread use for this purpose. This casting technique involves the formation of a mold into which the molten sterling silver alloy is poured. A mold may be created in the form to which the article will conform using the well known "lost wax" process.

[0036] Casting alloys into formed pieces using the lost wax process involves forming a mold by shaping a positive wax member into a wax tree. Removal of the wax from the wax tree forms the mold cavity or typically a series of interconnected cavities of the investment mold. This is achieved by placing the wax members and tree into a stainless steel tube or flask, which is filled with a mixture of plaster-of-paris and silica. The flask is then heated in an oven to approximately 1350°F to harden the mixture and to melt the wax for the removal thereof. The flask is then cooled slowly to cure the mold.

[0037] The alloy of the present invention may then be poured or cast in the mold at a temperature of about 2200°F so that the molten silver alloy enters the cavities in the mold and thereby forms the article(s). After cooling, the formed articles may be removed from the mold. This method allows for fine detail in complex pieces to be achieved and is often used in making complex articles of jewelry.

[0038] One problem associated with this method is that a certain amount of residue tends to remain in the trees after the article is removed therefrom. Using many conventional alloys it is not possible to recover the residue and add it back to virgin alloy for subsequent casting (reworked) without compromising the quality of the virgin alloy. However, it is possible, using the silver alloy of the invention, to rework residual alloy from the casting mold into virgin alloy. Significantly, it is possible to include up to about 50% of residual alloy in a virgin alloy and

maintain high quality of jewelry or other pieces formed therefrom. This advance represents a significant cost savings in the manufacture of cast articles.

[0039] Another problem associated with casting silver alloys is the occurrence of undesirable oxides. Silver has a known affinity for oxygen, which affinity increases with temperature. When exposed to air, molten silver will absorb about twenty-two times its volume of oxygen. Like silver, copper also has a great affinity for oxygen, typically forming copper oxide. This may be of the cupric or cuprous variety, or both. Air must be excluded during the casting process to avoid excessive porosity of the cast article or the presence of undesirable internal voids. Thus, in melting sterling silver and other silver-copper alloys, care must be taken to prevent oxidation.

[0040] Copper oxide, also known as fire scale, is typically a darkened portion which blemishes the cast article. Such fire scale is not limited to the surface of the cast article, as in the case of conventional tarnishes, but may penetrate the article to some depth. In some cases, such fire scale may not be removed by buffing and polishing. Moreover, the opportunity for the creation of fire scale exists when the alloy is initially formed as shot, when such shot is melted and recast to form the desired article, and subsequently if the cast article is thereafter annealed. In each of these cases, the alloy is heated, and, given the opportunity, may form fire scale.

[0041] As previously noted, fire scale is more than a surface tarnish. Rather, it is a blemish which may permeate the cast article for some depth, and, in some cases, may not be removed by polishing. To the extent that it exists, the blemish caused by fire scale may lead to the rejection of as-cast parts. Moreover, such rejected parts may have to be re-refined into the elemental metals, and re-alloyed. Another advantage of the silver alloys of the present invention is that they are not as susceptible to the formation of fire scale during casting, as are other known alloys, in part because the present silver alloys uses less copper.

[0042] It is also possible to form the alloy into an article by melting the combined elements to a suitable temperature, casting into bars, followed by rolling and other mechanical forming into a desired shape. The article so formed may be subsequently polished, buffed with a suitable polish, and washed to remove fats and oils.

[0043] It is often necessary to perform additional steps in treating silver alloys when forming them into pieces by rolling and the like. For example, it is often necessary to anneal or otherwise treat an alloy in order to successfully form it using rolling and other mechanical means, in order to allow the piece to be formed without cracking or other damage. When using the silver alloys of the present invention, it is often possible to omit such steps and still obtain a superior rolled or formed product. The silver alloys of the present invention possess a desirable combination of strength and malleability which allow for such effective and cost savings in the various forming processes.

[0044] Other methods of forming, molding or casting the alloy will be readily apparent to those having ordinary skill in the art and are within the scope of the invention.

EXAMPLES

[0045] The examples of the present invention presented below are provided only for illustrative purposes and not to limit the scope of the invention. Numerous embodiments of the invention within the scope of the claims that follow will be apparent to those of ordinary skill in the art from reading the foregoing text and following examples.

Example 1 - Silver Alloy of the Invention (QLS-7)

[0046] The following is an example of a silver alloy according to the present invention.

Example 1 - Formulation

Element	Weight (grams)	Weight %
Silver (Ag)	281.49	93.8300
Zinc (Zn)	13.5	4.5000

Element	Weight (grams)	Weight %
Copper (Cu)	3.75	1.2500
Indium (In)	0.3	0.1000
Gold (Au)	0.6075	0.2025
Tin (Sn)	0.135	0.0450
Iron (Fe)	0.027	0.0090
Silicon (Si)	0.105	0.0350
Manganese (Mn)	0.006	0.0020
Boron (B)	0.003	0.0010
Bismuth (Bi)	0.003	0.0010
Cobalt (Co)	0.003	0.0010
Chromium (Cr)	0.003	0.0010
Lead (Pb)	0.0075	0.0025
Vanadium (V)	0.0075	0.0025
Cerium (Ce)	0.0075	0.0025
Iridium (In)	0.030	0.0100
Zirconium (Zr)	0.015	0.0050

[0047] The silver alloy of Example 1 was made by heating 300 grams silver to at least its melting point followed by addition of the additional elements. Each element was added individually and allowed to melt before addition of the subsequent element. The molten metal was maintained at a temperature of 1750°F for 5 minutes. The alloy was then formed into an ingot and rolled into a sheet.

Example 2 - Silver Alloy of the Invention (QLS-8)

[0048] The following is an example of a silver alloy according to the present invention.

Example 2 Formulation

Element	Weight %
Silver (Ag)	93.85
Zinc (Zn)	4.50
Copper (Cu)	1.496
Indium (In)	0.10
Tin (Sn)	0.045
Iron (Fe)	0.009

[0049] The silver alloy of Example 2 was made in accord with the procedure described above for Example 1.

Example 3 - Comparative Example (QLS-9)

[0050] The following is an example of another commercially available sterling silver alloy obtained from the manufacturer (Leach and Garner, Attleboro, MA) in the form of a sheet.

Example 3 Formulation

Element	Weight %
Silver (Ag)	92.50
Copper (Cu)	6.60
Lithium (Li)	0.05

Example 4 - Comparative Example (QLS-10)

[0051] The following is a further example of a commercially available sterling silver alloy. This alloy was obtained from the manufacturer (Leach and Garner, Attleboro, MA) in the form of a sheet.

Example 4 Formulation

Element	Weight %
Silver (Ag)	92.50
Zinc (Zn)	5.10
Copper (Cu)	1.50
Tin (Sn)	0.85

Example 5 - Comparative Example (NAGAOKA)

[0052] The following is an example of a commercially available sterling silver alloy used in jewelry. This alloy was obtained from the manufacturer (Nagaoka Co., Ltd., Nagaoka, Japan) in the form of a sheet.

Example 6 - Comparative Example (ULTRAFINE)

[0053] The following is a conventional alloy used in jewelry and sold under the tradename ULTRAFINE SILVER™ (available from Stern-Leach, Attleboro, MA).

Example 6 Formulation

Element	Weight Percent
Silver (Ag)	99.76
Zinc (Zn)	0.0253
Copper (Cu)	0.3830
Iron (Fe)	0.0024
Silicon (Si)	0.0016
Manganese (Mn)	0.1671
Calcium (Ca)	0.0001
Cadmium (Cd)	0.0003
Sodium (Na)	0.0017
Nickel (Ni)	0.0019
Phosphorus (P)	0.0053
Palladium (Pd)	0.0005

[0054] The silver alloy of Example 6 was made by heating 300 grams of silver to at least its melting point followed by addition of the additional elements. Each element was added individually and allowed to melt before addition of the subsequent element. The molten metal was maintained at a temperature of 2012°F for 5 minutes. The alloy was then cast into rings. The forming step required substantial annealing.

Example 7 - Tarnish Resistance

[0055] The tarnish resistance of the alloys of Examples 1 and 2 were tested and compared to those of Examples 3 to 6. The following protocol was used to evaluate tarnish resistance.

[0056] A tarnish producing environment was created by adding a solution of ammonium polysulfide to a beaker and placing the beaker under a wire rack in a sealed chamber containing the test samples. The beaker was kept a suitable distance from test samples so that the hostile

fumes were evenly distributed throughout the sealed chamber. The atmosphere generated sulfide fumes at a concentration of about 10,000 ppm. The proper duration of exposure to reach maximum discoloration was evaluated by placing a control (non-tarnish-resistant sterling silver) in the tarnish producing environment and found to be six hours.

[0057] Polished and degreased samples made from alloys as described in the examples were placed upon a wire rack in the sealed chamber as described above. The samples were tested simultaneously in the same chamber to assure equality of exposure conditions. The samples were kept in the sealed container for 6 hours and then visually examined. The sample of Example 1 showed no visible discoloration. The sample of Example 2 showed only minor discoloration. The samples of Examples 3 to 6 were each severely blackened. The results show that the silver alloy of the present invention possesses superior tarnish resistance as compared to a conventional silver alloy.

Example 8 - Tarnish Resistance Over Time

[0058] Tarnish resistance over time of the alloy of Examples 1 and 2 as compared to that of Examples 3 to 6 was evaluated. After exposure to the tarnish producing environment as described above, the samples were allowed to remain in ambient air for 19 months. A visual inspection of the examples at the end of a 19 month test period are summarized in Table 4 below.

TABLE 4

Example	Visual Appearance after 19 Months
Example 1 (QLS-7)	No Tarnish
Example 2 (QLS-8)	Mild Tarnish
Example 3 (QLS-9)	Severe Tarnish
Example 4 (QLS-10)	Severe Tarnish
Example 5 (NAGAOKA)	Severe Tarnish
Example 6 (ULTRAFINE)	Severe Tarnish

[0059] After 19 months, the sample of Example 1 showed no visible discoloration. The sample of Example 2 showed only mild tarnishing. In contrast, the samples of Examples 3 to 6

were all severely tarnished. These results are shown in the figure, which is a photograph of the samples after exposure to the tarnish producing atmosphere and exposure to ambient air for 19 months thereafter. The results show that the silver alloys of the present invention possesses superior tarnish resistance as compared to conventional silver alloys.

[0060] Although illustrative embodiments of the present invention have been described herein with reference to the accompanying drawings, it is to be understood that the present disclosure is to be considered as exemplary of the principles of the invention and is not intended to be limited to those precise embodiments, and that various other changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention.